MULTI-BAND RING FOCUS ANTENNA SYSTEM

BACKGROUND OF THE INVENTION

Statement of the Technical Field

[0001] The invention concerns antenna systems, and more particularly ring focus antennas configured for concurrent multi-band operation.

Description of the Related Art

[0002] It is desirable for microwave satellite communication antennas to have the ability to operate on multiple frequency bands. Upgrading existing equipment to such dual band capability without substantially changing antenna packaging constraints can be challenging. For example, there can be existing radomes that impose spatial limitations and constraints on the size of the reflector dish. The existing antenna location and packaging can also limit the dimensions of the antenna feed system. For example, the existing radome can limit the forward placement of the feedhorn and the subreflector. Similarly, modifications to the existing opening in the main reflector are preferably avoided. As a result, for small aperture reflectors, the feed horn and the subreflector must fit in a relatively small cylinder.

[0003] In view of these spatial limitations, special techniques must be used to maintain antenna efficiency. U.S. Patent No. 6,211,834 B1 to Durham et al. (hereinafter Durham), concerns a multi-band shaped ring focus antenna. In Durham, a pair of interchangeable, diversely shaped close proximity-coupled sub-

reflector-feed pairs are used for operation at respectively different spectral frequency bands. Swapping out the subreflector/feed pairs changes the operational band of the antenna. Advantage is gained by placement of the shaped sub-reflector in close proximity to the feed horn. This reduces the necessary diameter of the main shaped reflector relative to a conventional dual reflector antenna of the conventional Cassegrain or Gregorian variety. The foregoing arrangement of the feed horn in close proximity to the sub-reflector is referred to as a coupled configuration.

[0004] The coupled configuration described in Durham generally involves sub-reflector to feed horn spacing on the order of two wavelengths or less. This is in marked contrast to the more conventional sub-reflector to feed horn spacing used in a decoupled configuration that is typically on the order of several to tens of wavelengths.

[0005] Although Durham demonstrates how a ring focus antenna may operate at different spectral bands, sub-reflector-feed pairs must be swapped each time the operational band of the antenna is to be changed. Accordingly, that system does not offer concurrent operation on spectrally offset frequency bands.

[0006] U.S. Patent No. 5,907,309 to Anderson et al. and U.S. Patent No. 6,323,819 to Ergene each disclose dual band multimode coaxial antenna feeds that have an inner and outer coaxial waveguide sections. However, neither of these systems solve the problem associated with implementing dual band reflector antennas in very compact antenna packaging configurations.

SUMMARY OF THE INVENTION

[0007] A compact multi-band antenna system includes a main reflector having a shaped surface of revolution about a boresight axis of the antenna. The main reflector is operable at a plurality of frequency bands spectrally offset from each other. For example, the higher one of the frequency bands can be Ka-band and the lower one of the frequency bands can be X-band.

[0008] A multi-band feed system provided for the main reflector includes a shaped non-linear surface of revolution about the boresight axis of the antenna. A plurality of feed elements are also provided. A first one of the feed elements for a high frequency band is installed at a first feed element location separated by a first gap from a vertex of the shaped non-linear surface of revolution on the boresight axis of the antenna. For example, the first gap can be more than about four wavelengths at a frequency defined within the first one of the frequency bands from the vertex to the feed aperture.

[0009] The first feed element can be decoupled from the shaped non-linear surface of revolution and illuminates the shaped non-linear surface of revolution. The shaped non-linear surface of revolution functions as a subreflector for the first feed element. The subreflector defines a ring-shaped focal region about the boresight axis for illuminating the main reflector at a first one of the frequency bands.

[0010] A second one of the feed elements for a lower frequency band can be installed at a second feed element location separated from the vertex on the boresight axis by a second gap. For example the second gap can be less than about

two wavelengths from the vertex of the shaped non-linear surface of revolution at a frequency defined within the second one of the frequency bands. Consequently, the second feed element is closely coupled to the shaped non-linear surface of revolution at a second one of the frequency bands.

[0011] The second feed element and the shaped non-linear surface of revolution can together form a single integrated coupled feed. The diameter of the focal ring of the main reflector at the lower frequency band is advantageously selected to be about the same size as the diameter of the shaped non-linear surface of revolution. Consequently, it is possible to use the single coupled feed to form a focal ring matched to the main reflector at the lower one of the frequency bands. In effect, the shaped non-linear surface of revolution in the single coupled feed performs as a splash plate. The single coupled feed also provides a transition from a circular to radial waveguide mode.

[0012] Notably, the single structure defining the shaped non-linear surface of revolution performs two very different functions at the two separate frequency bands. At the high band it functions as a sub-reflector whereas at the low band it functions as a splash plate defining part of the single coupled feed. In order to facilitate this result, the main reflector and the shaped non-linear surface of revolution can each have no continuous surface portion thereof shaped as a regular conical surface of revolution. Instead, these shapes can be numerically defined using computer modeling programs.

[0013] The invention can also include a method for operating a compact multi-band antenna system. The method can include the steps of providing a main

reflector having a shaped surface of revolution about a boresight axis of the antenna, forming a ring-shaped focal region about the boresight axis, and using a subreflector in the far field relative to a first feed element aligned with the boresight axis. Further, a second feed element can be aligned with the boresight axis in a nearfield position coupled to the sub-reflector to form in combination with the sub-reflector a single feed that transforms a circular waveguide mode into a radial waveguide mode for illuminating the main reflector. The first feed element can be selected to operate at a relatively higher band as compared to the second feed element. For example, the first feed element can operate within Ka-band and the second feed element can operate within X-band.

[0014] According to another aspect of the invention, the method can include positioning an aperture of the first feed element spaced more than about four wavelengths from a vertex of the shaped non-linear surface of revolution at a frequency within the first spectrally offset frequency band, and positioning an aperture of the second feed element spaced less than about two wavelengths from a vertex of the shaped non-linear surface of revolution at a frequency within the second spectrally offset frequency band. A focal ring of the main reflector can be advantageously selected to be about the same size as the shaped non-linear surface of revolution. The method can also include selecting the main reflector and the subreflector to have no continuous surface portion thereof shaped as a regular conical surface of revolution.

[0015] According to another aspect, the invention can include a method for feeding a compact main reflector of an RF antenna on a plurality of spectrally offset

frequency bands. The method can include the steps of forming a focal ring for a main reflector by positioning an RF source at a first frequency within a first frequency band in the far field relative to a shaped non-linear surface of revolution so that the shaped non-linear surface of revolution operates as a subreflector. A second focal ring can be formed for the main reflector by positioning a second RF source in the nearfield of the shaped non-linear surface of revolution. The second RF source can interact with the shaped non-linear surface of revolution to form a single feed network at the second RF frequency. The single feed network can form a coupled feed focal ring for the main antenna where the single feed network transforms a circular waveguide mode of said second RF source to a radial waveguide mode

BRIEF DESCRIPTION OF THE DRAWINGS

[0016] Fig. 1 is a schematic representation of a decoupled ring-focus reflector antenna design that is useful for understanding the invention.

[0017] Fig. 2 is a schematic representation of a coupled-feed ring-focus reflector antenna design that is useful for understanding the invention.

[0018] Fig. 3 is a schematic representation of a hybrid antenna system that combines the features of the antennas in Figs. 1 and 2.

[0019] Fig. 4 is an enlarged view of the feed system in Fig. 3.

DETAILED DESCRIPTION OF THE INVENTION

[0020] Ring focus antenna architectures commonly make use of a dual reflector system as shown in Fig. 1. With the dual reflector system, an RF feed 100 illuminates a sub-reflector 102, which in turn illuminates the main reflector 104. Sub-reflector 102 and main reflector 104 are shaped surfaces of revolution about a boresight axis 110 and are suitable for reflecting RF energy. Typical Cassegrain and Gregorian type reflector systems commonly use feed horns and sub-reflectors arranged in accordance with a decoupled configuration. These are sometimes referred to as decoupled feed/subreflector antennas.

[0021] In a decoupled feed/subreflector antenna, the RF feed 100 is located in the far field of the sub-reflector 102. For example, the aperture 106 of the RF feed 100 can be positioned spaced from a vertex 108 of the sub-reflector 102 by a distance at the frequency of interest, where s1 is greater than or equal to about four wavelengths. Since the RF feed is in the far-field, the decoupled feed/subreflector configuration lends itself to optical design techniques such as ray tracing, geometrical theory of diffraction (GTD) and so on.

[0022] A second known type of ring focus antenna system illustrated in Fig. 2 is known as a coupled-feed/sub-reflector antenna. Similar to the antenna in Fig. 1, this type of antenna makes use of a sub-reflector 202 and main reflector 204 that are shaped surfaces of revolution about a boresight axis 210 and are suitable for reflecting RF energy. In this type of antenna, the RF feed 200 and the sub-reflector 202 are spaced more closely as compared to the decoupled configuration. An aperture 206 of the RF feed and the vertex 208 of the sub-reflector 202 can be

spaced apart by a distance s2 that is typically less than about 2 wavelengths at the frequency of interest. When arranged in this way, the RF feed 200 and the sub-reflector 202 are said to be coupled in the near-field to generate what is commonly known as a "back-fire" feed.

[0023] In a back-fire feed configuration, the RF feed 200 and the sub-reflector 202 in combination can be considered as forming a single integrated feed network. This single feed network is particularly noteworthy as it provides a circular to radial waveguide transition that generates a prime-ring-focus type feed for the main reflector 204. In this regard, the back-fire feed can be thought of as being similar to a prime-focus parabolic feed. Further, the sub-reflector 202 in this feed configuration is not truly operating as a reflector in the conventional sense but rather as a splash-plate directly interacting with the feed aperture 206.

[0024] The ring focus antenna in Fig. 2 can employ a shaped-geometry main reflector and a shaped-geometry sub-reflector feed similar to the arrangement described in U.S. Patent No. 6,211,834 B1 to Durham et al., the disclosure of which is incorporated herein by reference. In Durham et al., interchangeable, diversely shaped close proximity-coupled sub-reflector/feed pairs are used with a single multi-band main reflector for operation at respectively different spectral frequency bands. Swapping out the sub-reflector/feed pairs changes the operational band of the antenna.

[0025] Each of the main reflector and the sub-reflector in the system described in Durham et al. are respectively shaped as a distorted or non-regular paraboloid and a distorted or non-regular ellipsoid.

[0026] The present invention combines the concept of the decoupled feed/subreflector antenna in Fig. 1 and coupled feed/subreflector antenna in Fig. 2 to provide multi-band capability in a very compact design. As shown in Fig. 3, a single main reflector 304 and a single sub-reflector 302 can be used concurrently with a set of RF feeds 300, 301 for two spectrally offset RF frequency bands. In particular these can include a lower frequency band serviced by RF feed 300 and a higher frequency band serviced by RF feed 301. The RF feeds 300, 301 and the subreflector 302 together comprise a hybrid feed 303 that is specifically designed to be concurrently used with shaped main reflector 304. The main reflector 304 and the sub-reflector 302 are each shaped non-linear surfaces of revolution. In general, the shape of the main reflector and the sub-reflector are not definable by an equation as would normally be possible in the case of a regular conic, such as a parabola or an ellipse. Instead, the shapes are generated by executing a computer program that solves a prescribed set of equations for certain pre-defined constraints.

[0027] The RF feeds 300, 301 can be advantageously coaxially located along a boresight axis 310 of the antenna as shown. Each is separated from the vertex 308 by a respective gap s3 and s4. The RF feed 301 is preferably in a location along the boresight axis 310 that it is in the far-field of the subreflector 302 and therefore decoupled with respect thereto. RF feed 300 is in a location along the boresight axis that it is in the near field of the sub-reflector 302 and is therefore said to be coupled to the sub-reflector. For example, the gap s4 for RF feed 301 can be more than about four wavelengths at a frequency defined at the low end of

the high frequency one of the frequency bands from the vertex 308 to the feed aperture 312. By comparison, the gap s3 between the vertex 308 and the aperture 314 for the RF feed 300 can be less than about 2 wavelengths and preferably about one wavelength at a frequency defined within the lower one of the frequency bands.

[0028] Using techniques similar to those disclosed in Durham et al., the sub-reflector 302 and the main reflector 304 can be advantageously shaped using computer modeling and a set of predefined constraints to allow the coaxially located RF feeds 300, 301 to concurrently function with the single sub-reflector 302 and single main reflector 304. Advantageously, this can be accomplished with the two RF feeds 300, 301 located at different relative distances from the vertex 308 and operating on different frequency bands. For example, the higher frequency one of the frequency bands can be Ka-band and the lower one of the frequency bands can be X-band.

[0029] The subreflector 302 advantageously defines a ring-shaped focal point about the boresight axis for illuminating the main reflector with RF generated by RF feed 301 at the higher one of the frequency bands. The feed element 300 and the shaped non-linear surface of revolution defined by the sub-reflector 302 can together form a single integrated coupled feed that also provides a transition from a circular to radial waveguide mode.

[0030] According to a preferred embodiment, the diameter of the focal ring of the main reflector at the second frequency and the diameter d of the shaped non-linear surface of revolution defining the sub-reflector 302 are advantageously

selected to be about the same size. If they are not, the coupled feed focal ring will not be coincident with the single main focal ring defined by the main antenna. Further, the diameter d1 of the subreflector 302 is preferably not much larger than the diameter d2 of RF feed 300. Using these guidelines, it is possible to use the single coupled feed comprised of subreflector 302 and RF feed 300 to form a focal ring suitably matched to the main reflector at the frequency band of the feed 300.

[0031] Notably, the single subreflector 302 defined by the shaped non-linear surface of revolution performs two very different functions at the two separate frequency bands. At the high band (RF feed 301) it truly functions as a sub-reflector whereas at the low band (RF feed 300) it functions more as a splash plate defining part of the single coupled feed.

[0032] In order to facilitate the use of sub-reflector 302 and main reflector 304 concurrently on the two separate frequency bands, they must each be shaped so as to have no continuous surface portion thereof shaped as a regular conical surface of revolution. According to a preferred embodiment, the precise shape of the main reflector 304 and the sub-reflector 302 can be determined based upon computer analysis.

[0033] According to a preferred embodiment, a computer program can be used to determine suitable shapes for the sub-reflector 302 and the main reflector 304. This process generates a numerically defined dual reflector system as shown and described relative to Fig. 3. The resulting shape of the main reflector is a conical surface of revolution that is generally, but not necessarily precisely,

parabolic. The resulting shape of the sub-reflector is likewise a conical surface of revolution that is generally, but not necessarily precisely, elliptical.

[0034] Given the prescribed positions of RF feeds 300, 301 and boundary conditions for the antenna, the shape of the sub-reflector 302 and the main reflector 304 are generated by executing a computer program that solves a prescribed set of equations for the predefined constraints. Physical constraints drive some of the boundary conditions, such as the size of the subreflector 302 and the size of the main reflector 304. Electromagnetic constraints drive other boundary conditions. For example, if the electrical spacing of the phase center for RF feed 301 to subreflector 302 is less than about four wavelengths at the high frequency band, then the operation of the subreflector will no longer behave optically and the system will not perform properly. Similarly, if the feed phase center is too far from the subreflector 302, then the low band feed will block the line-of-site between the phase center of RF feed 301 and subreflector 302 and the high band system will not perform properly. Further, the throat 330 of the feed 300 must be at or behind the aperture 312 of RF feed 301.

[0035] Given the foregoing constraints, equations are employed which: 1--achieve conservation of energy across the antenna aperture, 2--provide equal phase across the antenna aperture, and 3--obey Snell's law. Details regarding this process are disclosed in U.S. Patent No. 6,211,834 to Durham et al.

[0036] For a given generated configuration of RF feed 300 and a given set of shapes for the sub-reflector 302 and the main reflector 304, the performance of the antenna is analyzed by way of computer simulation. This analysis determines

whether the generated antenna shapes will produce desired directivity and sidelobe characteristics for the low frequency band associated with feed 300. RF matching components are used to achieve the desired return loss.

[0037] If the design performance criteria are not initially satisfied for the lower frequency band, one or more of the equations' parameter constraints are iteratively adjusted, and the performance of the antenna is analyzed for the new set of shapes. This process is iteratively repeated, as necessary until the shaped antenna sub-reflector shape and coupling configuration, and main reflector shape, meets the antenna's intended operational performance specification.

[0038] This iterative shaping and performance analysis sequence is also conducted for another (spectrally separate) band, such as Ka-band to realize a set of sub-reflector and main reflector shapes at the higher frequency operational band. The higher band of operation associated with RF feed 301 is advantageously configured with a sub-reflector/feed element configuration that is decoupled as show in Fig. 3.

[0039] Each of the feed configurations, and the shapes for the subreflector and main reflector may be derived separately, as described above. According to a preferred embodiment, however, it is possible to first derive a first set of shapes for main reflector 304 and sub-reflector 302 for the lower frequency band based on a first feed configuration. These shapes can then be used to derive the feed configuration for the higher frequency band that is necessary to achieve the required antenna performance. The foregoing approach can achieve good efficiencies and sidelobe performance results on both of the bands.

[0040] Fig. 4 is an enlarged view of the hybrid feed 303 which shows RF feeds 300, 301 in more detail. RF matching features 326 can be provided for the RF feed 301 on a flared portion of RF feed 300. RF matching features 328 for RF feed 300 can also be formed on a throat portion of the RF feed 300. Subreflector supports 322 can be provided along an outer perimeter of the feed system to minimize interference with the operation of the feed. The subreflector supports 322 are preferably formed of a dielectric material to minimize interaction with the operation of the feed. Fig. 4 also shows details of an RF packaging can 320.

[0041] Finally, it should be noted that while the antennas described herein have for convenience been largely described relative to a transmitting mode of operation, the invention is not intended to be so limited. Those skilled in the art will readily appreciate that the antennas can be used for receiving as well as transmitting.